Sustainability in Rice Weed Management

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Abstract

For a number of years in Asia, there has been a problem of degradation of the environment and declining rice productivity in paddy fields. This has been accompanied by declining profitability and declining incomes from rice farming. In the future, there will be a need to greatly improve productivity while maintaining the sustainability of that increased productivity. The problem of sustaining productivity growth is caused by inadequate attention to understanding of and response to the physical, biological and ecological consequences of agricultural intensification. Intensification in rice production and changes in the methods of planting rice have resulted in changes in weed populations, emergence of new weed problems, including weedy forms of rice, and increased herbicide usage. There is increasing concern about the externalities of intensive rice production. Sustaining input use efficiency is closely related to understanding changes in the paddy system with intensification. Information will be required on the components of the weed flora, the effects of levels of weed infestation on crop performance and the efficacy and cost of potential means of control. Weeds have a strong impact on rice production and there are few practical alternatives to heavy reliance on tillage, high planting densities, water and herbicides for weed control. The challenge for weed research is to develop control strategies that maintain or enhance farm profits while safeguarding the environment and human health.

Introduction

As we look toward 2020 and beyond, the world must confront three central intertwined challenges: alleviating widespread poverty, meeting current and future food needs and managing the natural resource base to ensure sustainability. Compounding the difficulty of meeting these challenges is the expected addition of almost 100 million people to the world's population every year for the next 30 years and the limited availability of new land for cultivation in much of the world (Pinstrup-Andersen and Pandya-Lorch, 1994). The challenge is how to feed an increasing population without irreparably damaging the natural resource base on which agricultural production depends (Ehui and Hertel, 1989).

Rice, which is produced in a wide range of locations and under a variety of climatic conditions, is most closely associated with the South, Southeast and East Asian nations extending from Pakistan to Japan. It is one of the most important crops in the world, providing 20% of global human per capita energy and 15% of per capita protein (IRRI, 1993).

For a number of years in Asia, there has been a problem of degradation of the environment and declining rice productivity in paddy fields. This has been accompanied by declining profitability and declining incomes from rice farming. In the future, there will be a need to greatly improve productivity while maintaining the sustainability of that increased productivity. The problem of sustaining productivity growth is caused by inadequate attention to understanding of and response to the physical, biological and ecological consequences of agricultural intensification (Pingali, 1991).

Intensification in rice production and changes in the method of planting rice have resulted in changes in weed populations, emergence of new weed problems, including weedy forms of rice, and increased herbicide use. There is increasing concern about the externalities of intensive rice production.

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Problems

Undesirable weed shifts

The recent changes from transplanting to direct seeding of rice in Asia have resulted in dramatic changes in the types and intensity of weeds and their distribution. Studies conducted in Malaysia clearly show that direct seeding techniques cause weed populations to shift from less competitive broadleaved weeds to more problematical grasses. Weed surveys in the Muda area revealed that in the late 1970s when direct seeding was in the incipient stage of development (less than 1% of the planted area), there were 21 weed species belonging to 13 families. The hierarchical order of dominance was *Monochoria vaginalis* (Burm. f.) Presl > *Lndwigia hyssopifolia* (G. Don) Exell > *Fimbristylis miliacea* (L.) Vahl > *Cyperus difformis L.* > *Limnocharis flava* (L.) Buch. (Ho and Zuki, 1988). In the first season in 1989, when 82% of the area was direct-seeded, 57 weed species belonging to 28 families were recorded. The order of severity was *Echinochloa crus-galli* (L.) P. Beauv. > *Leptochloa chinensis* (L.) Nees > *F. miliacea* > *Marsilea minuta* L. > *M. vaginalis* (Ho and Itoh, 1991).

Similar results have been observed in Korea. Kim (1992) reported a two- to three-fold increase in weed biomass and a shift in the dominant weed species to C_4 grass weeds in direct-seeded rice compared to transplanted rice.

The continuous adoption of a particular practice inadvertently contributes to the shift in dominance and distribution of rice weeds. In the formulation of any weed management program, it is imperative that the recommended production practices be systematically manipulated and synchronized with the current location-specific farming activities. In this way, the most effective weed management is obtained (Ho *et al*., 1994).

A program of weed control does not usually simply remove one species from within a community but will alter the relationships between the constituent species by disturbing the environment, altering competitive interactions or creating stress thus disturbing the natural pattern of development change occurring in the community (Cook, 1990).

The use of herbicides moves the agroecosystem toward low species diversity which is contrary to the high species diversity of the natural ecosystem. Mahn and Helmecke (1979) stated that reliance on a single herbicide could result in quantitative changes in the structure of the weed population in as few as 5 years.

In Korea, since 1980, 140–150% of the irrigated rice area (100–120% of the total rice area) has been treated with herbicide annually. However, there has been too much reliance on a single herbicide. From 1975 to 1989, butachlor accounted for more than 50% of the tota 1 herbicide used, peaking in 1986 at 80%. This has resulted in undesirable weed shifts (Kim, 1994).

Increased herbicide use

The importance of weeds in rice production is likely to increase rather than decrease with continuing population-induced increases in land use intensity. The pressing need to raise yields and maintain profits on a progressively limited land base has paved the way for herbicide use in Asian rice production. Farmers are not left with little choice but to cut labour and production costs, particularly for the most labour-intensive tasks, such as planting and weeding. As a result, herbicides are being substituted widely for manual labour as a method of weed control. This trend has been reinforced by the spread of direct-seeded rice that requires chemical weed control in the early stages of crop growth to prevent substantial yield losses and by a decreasing ability in some systems to control weeds through water control as a consequence of reduced water supplies and deteriorating irrigation structures (Naylor, 1994).

According to Woodburn (1993), it is realistic to expect that over the next 6 to 8 years, the average global expenditure on rice herbicides could exceed \$ 10/ha compared to \$ 7.50 at present resulting in an increase in the rice herbicide market in China and India from \$ 67 million to over \$ 550 million. Herbicides will represent the major growth area in the pesticide industry in the developing countries in the next decade.

The steady emergence of herbicides as a preferred technology for weed control in Asian rice systems follows a 20-year period of widespread growth in insecticide use that is just beginning to subside. Asian farmers now realize that their dependence on insecticides has often been unnecessary, expensive and sometimes even dangerous. Although herbicides are much less toxic and persistent than the majority of insecticides used in Asian rice production, the inevitable question arises: "Twenty years from now, will Asian societies regret having gone down the herbicide path ?" (Naylor, 1994).

Weed resistance to herbicides

One important development as a result of continued use of the same herbicide is the evolution of weed species that have developed resistance to herbicides.

In Malaysia, a resistant form of *F. miliacea* has been found in rice fields where 2, 4-D has been applied for 25 years; the weed cannot be controlled with six times the recommended rate of 2, 4-D (Watanabe *et al*., 1994). Butachlor-resistant *E. crus-galli* has been reported in China (Huang and Lin, 1993). More resistance is observed where butachlor has been applied for 8-12 years and where two rice crops are grown per year.

Resistance is expected to become a much more serious economic problem within the next 5 to 10 years (LeBaron and McFarland, 1990). The problem can be avoided or reduced by exploiting a wide range of crop protection measures rather than over-relying on chemical inputs (Tan *et al*., 1992).

Externalities

Despite the increasing use of herbicides in rice fields in South and Southeast Asia, there is surprisingly little information on their external effects. Externalities have a value because people who can afford it are willing to pay for health and happiness, for clean water, fresh air and healthy food (Zadoks, 1992).

1. Water One of the main problems associated with the use of chemicals is to ensure that there is no pollution of water for its many uses. Caution must be used when applying herbicides in floodwater to avoid movement of the herbicide into groundwater or to prevent treated water from contaminating other water sources as it drains from treated fields (Bayer, 1991).

In intensively cropped areas, agrochemicals are reaching shallow aquifers and contaminating groundwater. Castañeda and Bhuiyan (1995) reported that 24% of the groundwater samples collected from shallow tubewells within rice field boundaries were contaminated with butachlor, the maximum concentration in a single sample being 1.14 ppb. Present concentrations are much below dangerous levels but it is only a matter of time before toxic levels are reached. Studies are needed to understand the processes of agrochemical movement and contamination of the water resource base and to predict trends under alternative management options (Bhuiyan, pers. comm.).

2. Health In Malaysia, 51.3% of farmer respondents said that they had experienced symptoms associated with pesticide poisoning. The highest incidence (24.8%) was due to herbicides, mainly 2, 4-D and paraquat. Headaches and dizziness were the most frequently mentioned symptoms. Drinking of coconut water was the main (73.6%, n=120) remedial action. Only 12.8% consulted a medical doctor for treatment (Ho *et al*., 1990).

Other factors

1. Risk Risk considerations can be important in determining farmers' choice of weed control methods and intensity of control in rice fields. Unlike other inputs such as water and fertilizers, weed control inputs are "protective" in the sense that they help reduce damage. Such inputs are generally considered to be "risk-reducing". Depending on the source of uncertainty, herbicides could be risk-reducing or risk-increasing (Pandey and Medd, 1991; Horowitz and Lichtenberg, 1994). To the extent they actually reduce risk, risk-averse farmers would tend to apply more weed control inputs than risk-neutral farmers.

Risk aversion could also be an important factor in determining the level of weed control inputs applied by rice farmers. Weed management practices which function effectively only under very precise conditions may be perceived to be too risky by farmers. For example, in the Mekong Delta in Vietnam, farmers do not like to use pretilachlor + fenclorim for weed control in wet-seeded rice because of the narrow application window (it has to be applied at 3-4 days after seeding). In the Philippines, farmers use low levels of weed control inputs even though the marginal benefit-cost ratio associated with high intensity weed control practices is large. In addition to credit constraints, such a behavior could be due to risk aversion.

2. Economics Herbicides are a highly productive input and the marginal return for every dollar invested in herbicides is strongly positive. This is consistent with increasing sales volumes of herbicides.

To the extent that herbicides are made cheaper relative to labour due to distortionary price policies, substitution of herbicides for labour is socially undesirable. In addition, negative environmental and health effects of herbicide use entail additional social costs.

The acceptability of more sustainable production systems is largely dependent upon success or failure in managing weeds. Assuming the development and successful implementation of novel agricultural systems that are biologically diverse and have reduced requirements for purchased inputs, economics will continue to dictate efficient weed management in the foreseeable future (Bridges, 1995).

Possible solutions

Herbicide rate

Farmers in most countries in South and Southeast Asia apply herbicides at less than the recommended rate (Navarez and Moody, 1979; Abeyratne *et al*., 1984; van de Fliert and Matteson, 1990). In a number of experiments conducted at the International Rice Research Institute and in farmers' fields in the Philippines, application rates of preemergence herbicides, such as butachlor and pretilachlor + fenclorim, could be reduced by up to 50% of that recommended without loss in efficacy or reduction in crop yield (Mabbayad and Moody, 1985; Castin *et al*., 1992; Pablico and Moody, 1993).

It is possible to reduce the recommended rate because it is often based on worst case situations for the weed species most difficult to control under unfavourable climatic conditions. However, the worst case approach is no longer acceptable. Instead, the rate should be adjusted to give exactly the required effect and no more under the prevailing conditions.

Amount of herbicide applied

The amount of herbicide applied can be reduced by using more effective herbicides applied at lower rates and by improving application equipment. Advances in application technology should reduce over application and drift and, therefore, reduce environmental contamination.

Recently developed herbicides that are applied at low rates and have low mammalian toxicity reduce the risk of environmental contamination. Application rates have been reduced from 1.8-3.0 kg/ha to 20-50 g/ha (Kim, 1994).

Appropriate herbicide selection is another way to reduce herbicide use. In many cases, in Korea, only one inexpensive herbicide application is needed (e.g., butachlor, thiobencarb or chlomethoxyfen for *Echinochloa* spp., *M. vaginalis* or other annual weeds; piperophos + dimethametryn for *Potamogeton distinctus* A. Benn.; and bentazon for *Eleocharis kuroguwai* Ohwi) rather than expensive and systematic applications of a number of herbicides (Kim, 1994).

Use of postemergence herbicides

Postemergence herbicides are generally used at lower rates than preemergence herbicides and most have low to very low groundwater contamination potential (Worsham, 1991).

Risk considerations are important in the choice of preemergence versus postemergence herbicides. Preemergence herbicides have to be applied before weeds emerge; the application is prophylactic. On the other hand, postemergence herbicide use is more flexible because it can be tuned to the level of infestation. Farmers may, however, opt for prophylactic applications if they believe that postemergence control is too risky.

Crop rotation

Many weeds thrive best and cause the most trouble when the same crop is grown year after year. Some weeds are associated with certain crops or grow only in special habitats. Crop rotation or changing the habitat interferes with the normal life cycle of many weeds. Various systems of crop rotation have been employed from time to time. Many are useful for controlling weeds but the practicability of any specific method for a particular locality must be determined by considering such factors as climate, rainfall, suitability of soil, availability of markets and opportunity for utilizing or disposing of the crops. The success of a system of rotation, as far as the control of weeds is concerned, depends largely on the thoroughness and persistence with which the cultivated crop is kept free from weeds rather than on the kind of crop (Muenscher, 1960).

Allelopathy

Since plants are known to self-regulate their densities and distribution in nature through allelopathic interactions, attention is now being given to the possibility of exploiting this phenomenon to aid in placing crops in a more favourable competitive position over weeds (Worsham, 1989).

Dilday *et al.* (1991) reported that 347 accessions from the USDA/ARS rice germplasm collection exhibited allelopathic activity to *Heteranthera limosa* (Sw.) Willd. Lin *et al.* (1993) found that six allelopathic rice lines reduced the dry weight of aquatic weeds from 93 to 99% compared with Rexmont, a cultivar without allelopathic activity.

Fujii (1992) screened 189 rice cultivars for allelopathic activity, using lettuce as the assay crop, and found distinct differences between cultivars. Improved Japonica cultivars showed little allelopathic activity; traditional Javanica rice cultivars and red rice strains showed strong activity. The allelopathic activity of *Oryza glaberrima* Steud. was also strong.

Mulching

The phytotoxic potential of crop residues could be exploited in management of various weeds in agroecosystems. Dilday *et al.* (1992) reported that allelochemicals were present in straw of rice accessions that showed allelopathic activity in the field to *H. limosa.* Rice germplasm with high allelopathic activity combined with its straw incorporated into soil controlled *Cyperus iria* L. almost as effectively as a tank mixture of propanil + bentazon (Lin *et al.*, 1992).

Khan and Vaishya (1992) reported that residues of rice cv. Sarjdo-52 incorporated 5～6 cm deep at 5 t/ha reduced populations of *Echinochloa colona* (L.) Link and broadleaved weeds (*Ammannia baccifera* L., *A. multiflora* Roxb. and *Phyllanthus fraternus* Webster) by 40 and 56% , respectively and their biomass production by 39 and 64% whereas germination and biomass production of *Fimbristylis dichomata* (L.) Vahl and *F. ovata* (Burm. f.) Kern were stimulated.

Biological control

Augmentive biological control of weeds refers to the utilization of endemic natural enemies against endemic weed species or exotic weed species which were introduced long ago and have become naturalized in the present habitat. In the bioherbicide approach, excesses of pathogen inoculum are applied to the entire population of an indigenous weed in the same manner as chemical herbicides, causing infection and death of the contacted host plants.

Only one microbial herbicide, an endemic fungal pathogen, *Colletotrichum gloeosporioides* (Penz.) Sacc. f. sp. *aeschynomene*, is registered for the control of a weed [*Aeschynomene virginica* (L.) B. S. P.] in rice in the United States. However, this product is no longer manufactured because it is too expensive.

Pathogens that have shown potential as biological control agents for controlling weeds in rice in Asia include *Drechslera monoceras* (Drechsler) Subram. & Jain for the control of *E. crus-galli* (Gohbara and Yamaguchi, 1992), *Epicoccosorus nematosporus* Yokoyama et Suzuki for the control of *E. kuroguwai* (Gohbara and Yamaguchi, 1992), and a leaf blight pathogen for the control of *Sphenoclea zeylanica* Gaertn. (Bayot *et al.*, 1992).

Although bioherbicides produce no environmental contamination or toxicity to humans, their selectivity can be a disadvantage because each agent controls only one weed species. Other problems include the difficulty of commercially producing and formulating the organism while maintaining its viability (Ho *et al.*, 1994). The use of naturally occurring enemies such as plant pathogens appears to offer an environmentally friendly natural solution to weed problems. In practice, however, there are many problems associated with their development and effective use that will probably prevent them from becoming a significant method of weed control in arable crop production at least until the year 2000 (Williams, 1992).

Cover crops

The use of cover crops is increasing in popularity as farmers become more concerned with the need to reduce inputs and protect the quality of their farm environments. In addition to providing on-farm sources of nitrogen and organic matter, legumes may decrease soil erosion, improve soil physical characteristics, increase cropping system biodiversity and increase yields. Mallick (1981/82) reported that using *Sesbania bispinosa* (Jacq.) W. F. Wight as a green manure resulted in a reduction in weed growth.

The mechanisms of weed suppression by cover crops are complex. Cover crop residues can inhibit weeds through purely physical influences such as reduction in light or soil temperature. Living cover crops may interfere with weeds through competition for limited growth requisites. Allelopathic interference through the release of chemicals from plants or residues may also be involved (Hoffman and Weston, 1995).

Integrated weed control

Increasing herbicide use is likely to result in a move from integrated weed control to a "simple" weed control technology. Factors such as herbicide-resistant weeds, build-up of tolerant weed species and environmental contamination will result in greater integration of weed control practices. A balance between the two must be reached taking into consideration all the factors involved.

Weeds are most effectively controlled by the simultaneous application of a variety of practices, the total effect of which is usually greater than the effects of individual measures employed separately. Lower herbicide rates or better herbicide performance is achieved when optimum cultural practices are used.

Conclusions

Rice fields form a recurring part of the landscape of many countries and rice provides sustenance to more people than any other cereal. The wise use of rice fields is, therefore, a worthy objective (Fernando, 1980).

At present, there is no package of technology available to transfer to producers that can assure the sustainability of growth in agricultural production at a rate that will enable agriculture, particularly in the developing countries, to meet the demands being placed on them (Ruttan, 1988).

Growth of agricultural production is not incompatible with natural resource protection. The growth path must be based on technologies that do not exploit the resources and make maximal use of the biological potential (de Haen, 1991). The research agenda on sustainable agriculture needs to define what is biologically feasible without being excessively limited by present economic constraints (Ruttan, 1991).

Agriculture will be made more sustainable not by going back but by drawing on the best from the past and the best of modern technology (Fawcett, 1995). Sustainable agriculture supports a system of agriculture that over the long term, improves environmental resources such as soil and water, creates a healthful and plentiful food supply, is not harmful to farmer health and fosters a system of agriculture that is supportive of economically viable rural communities (Wyse, 1995).

The composition of weed communities of arable land is a reflection of the production and management practices imposed on the land. Trends towards reduced tillage, reduced herbicide use, intensified rotations, organic sources of nutrients and other changes in production practices change the environment where weeds are managed, compete and reproduce. Modifying crop management inputs will result in an altered competitive environment in which morphological and physiological traits that confer success will shift. These changes must be taken into consideration to develop economically and environmentally sound weed management systems (Buhler, 1995).

The importance of weeds in rice production is likely to grow rather than diminish with continuing population-induced increases in land use intensity. Rice weed control problems are compounded by growing water scarcities and by the rapid shift from transplanting to direct seeding. Herbicide use is expected to keep growing as farmers shift out of hand weeding in response to rising wage rates.

No single weed control technique is perfect and because the weed population constantly adapts to its physical environment, a multilateral approach is required to ensure sustainability. There is a need to find ways to reduce dependency on herbicides. New weed control strategies must be found to balance the use of herbicides with environmental protection and the production of food safe for human consumption.

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Discussion

Chou, C.H. (Taiwan): This is an excellent paper reviewing the current performance of herbicide use in agroecosystems. The increasing amount of herbicides used in agricultural land may result in a rapid deterioration of the environment. Therefore, emphasis should be placed on research dealing with the use of potential allelopathic compounds in some plants. By using transgenic techniques, transfer of most of the potential allelopathic genes into major crops could be achieved.